Evaluating an Emergency Management Decision Support System with Practitioner-Driven Scenarios: Action Design Research

Completed Research Paper

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Abstract

Evaluating an IT artifact is essential in design science, as it serves to validate that a solution has achieved the purpose for which it was designed. This paper presents the evaluation of an emergency management (EM) decision support system (DSS). The DSS addresses the informational needs of strategic-level decision makers in the event of large-scale disasters. Disasters, by their very nature, are complex and unpredictable, require emergency responders to make rapid high risk decisions with the potential for life threatening and economically devastating results. This study details a phased evaluation using three scenarios: (1) Biological Hazard Response, (2) Cross-Border Chemical Explosion and Bio-Hazard, and (3) Regional and Interregional Mass Flooding. The mixed method evaluation elicited participant feedback to test usability and utility, guided by action design research. To ensure parity between scenarios, an existing EM framework informed scenario design with the unique addition of the DSS to support end-user processes.

Keywords: Emergency management, decision support system, system evaluation, design science, action research, scenarios

Introduction

Evaluation of an IT artifact is an important component of design science research (DSR) (Peffers et al., 2012) as it serves to collect the necessary evidence that a developed solution has achieved the purpose for which it was designed (Ostrowski and Helfert, 2012). In this case, it serves to validate the end-user requirements of stakeholders from the emergency management (EM) domain for a decision support system (DSS), designed to support strategic decision-makers during large-scale and cross-border disasters. EM serves to reduce vulnerabilities to hazards, so that affected regions can respond to and recover from disasters, which may be natural (e.g. hurricanes, earthquakes, etc.) or man-made (e.g. terrorist attacks, explosions, etc.) (Fogli and Guida, 2013). To be classified as a disaster, an event must exceed the ability of the region to cope with negative societal and environmental effects (Chou et al., 2014; Nouali-Taboudjemat et al., 2009). The design of appropriate information systems (IS) represents an opportunity to support emergency services in the management of large-scale incidents. Decision support (DS) is an important IS contribution, as the decisions made in response to a disaster have major consequences on a vulnerable population in the short and long term, in the case of life-threatening situations, and with potential for economic and environmental consequences (Bharosa et al., 2010; Johnson, 2000; Neville et al., 2013). Therefore, decisions must be based on accurate, timely, and readily accessible information. It has become increasingly apparent that "Interdisciplinary and multi-stakeholder collaborations are critical for enhancing situational awareness among affected-populations, emergency responders, decision-makers, and volunteers" (Liu, 2014, p. 392). Hence, there is a need for systems that support distribution of relevant information across multiple agencies to create a shared operational picture. But it is not an easy fix, as these situations come with unpredictable outcomes in the face of extreme uncertainty (Turoff et al., 2008) and are often coupled with interoperability challenges between the different response units, due to their individual infrastructures, policies, processes, and language. With its complicated nature, a viable solution continues to be sought by both practitioners and scholars (Kapucu et al., 2010).

Applying a DSR approach in conjunction with action research methods, this project develops a comprehensive DSS to support rapid and effective decision-making at all stages of the EM lifecycle (Alexander, 2012) from mitigation and preparedness (pre-disaster) to response and recovery (post-disaster). Action Design Research (ADR) was applied due to the complex nature of the problem and to meet the needs of the interdisciplinary project partners. The partners are from several countries and institutions: Third Level Universities from Ireland (Health; IS), Sweden (Informatics), Austria (Innovation and Technology Management; Knowledge Technologies); Health and Emergency Services from Ireland, Israel, and Northern Ireland (UK); and a specialist consultancy firm in Ireland (Spatial Planning). The project seeks to meet the EM sectors' needs from a practitioner-driven and interdisciplinary perspective to deliver DS tools that are tested, evaluated, and enhanced through quality, end-user designed emergency scenarios. To meet this objective, this paper addresses the following research question: How should an EM DSS be evaluated from a practitioner-driven perspective? Thus, the scope of the paper is to describe the process of system evaluation, from concept, to design and implementation. As it stands, there is a lack of guidance on how to conduct a DSR evaluation in the IS discipline (Pries-Heje et al., 2008; Peffers et al., 2012) and it has been noted there are very few examples of how to conduct an evaluation at the operational research level (Ostrowski and Helfert, 2012). Thus, a three-phased evaluation is presented, with three practitioner-driven scenarios, designed to demonstrate and evaluate the DSS with project end-users/partners and external EM practitioners (e.g. agencies, decision-makers, emergency responders, etc.). Each scenario represents a different emergency context and ultimately addresses a range of situations and stakeholder types. In the DSR literature, an illustrative scenario is defined as the "application of an artifact to a synthetic or real-world situation aimed at illustrating suitability or utility of the artifact" (Peffers et al., 2012, p. 402). In this paper, the scenarios were developed to be as realistic as possible, representing real-world emergencies based on actual incidents. The complementary goals of the scenarios were to, firstly, provide value to the participants by undertaking an exercise in an emergency scenario that required multiple agencies from different countries/regions to collaborate, while also showcasing and evaluating the artifact and its potential value in supporting strategic-level decision-making. Joint exercises between different countries/regions are extremely valuable to EM stakeholders as they are difficult to organize and for some agencies have never been attempted. Thus, the scenarios were designed with these goals in mind, so that EM stakeholders had the opportunity to undertake a worthwhile multi-agency exercise and the completed DSS modules could be evaluated under different circumstances with different end-user groups.

The scenarios were jointly created by the three end-user partners from the Health and EM Services in conjunction with the system developer partners. They were designed to test the full capacity of the proposed solution from early to final development. The scenarios addressed specific criteria and were designed to test module usability, module utility, and the integration of the tool-set. In order to ensure parity between scenarios, they were designed using the Irish Framework for Major Emergency

Management (MEM) and included the insertion of the DSS solution in the scenario to support end-user processes. It was agreed between the project partners that the Irish framework was the best fit to meet the needs of the three countries involved. The MEM framework represented a familiar workflow for the participants, who could then assess the system as an appropriate intervention to improve EM processes. The scenarios were created and executed in three regions: (1) Tel Aviv, Israel (cross-border element with Ireland); Dublin, Ireland (cross-border element with Northern Ireland, UK); and Cork, Ireland (interregional). The scenarios were a: (1) Biological Hazard Response, (2) Cross-Border Chemical Explosion and Bio-Hazard, and (3) Regional and Interregional Mass Flooding. The methodology consisted of both quantitative and qualitative feedback from participants, using survey questionnaires, participant observation, and general feedback through focus groups, debriefing sessions, and open-ended survey comments. Participants included a group of external stakeholders from various health and EM organizations representing experts in their field. The findings from each scenario informed the improvements and continued development of the DSS. The results were positive in nature and provided critical feedback for capability refinement. The survey results, respondent comments, and observations were used to create a number of lessons-learned for future scenario design.

Presenting the EM DSS Solution

The need for technological solutions to aid emergency management (EM) has been well established. Yet despite the much-touted benefits of computer-assisted decision support systems (DSS) for crisis management, the market for emergency management information systems (EMIS) remains fragmented. The EMIS ecosystem is characterized by many disparate solutions which vary significantly in terms of functionality, interoperability and focus. Neville et al. (2013) conducted an extensive study of commercially available European tools and the investigation revealed significant functionality gaps. The majority of available tools have been designed for implementation during the response phase of the EM lifecycle and were intended for use by practitioners at the operational decision-making level. Prominent functions available by many of the reviewed tools include intelligence gathering and situational awareness. However, they are not always available across all decision-making levels or are targeted at individual phases of the EM lifecycle (e.g. Vector Command, MapyX Ltd., SAR Technology, WebEOC, NEMSIS, Fortek, ESRI …)

EM systems need to be complex and multifaceted as they "need to deal with multiple types and multiple stages of disasters, various stakeholders, and numerous issues" (Chou et al., 2014, p. 998). These systems often lack interoperability – with the literature categorizing many EM systems as fragmented, localized, and technologically disconnected (Chen et al., 2013). It is crucial that systems support the sharing of relevant information across agencies to help create a shared operational picture and effectively facilitate the coordination of emergency responders, decision-makers, volunteers, and affected populations (Liu, 2014). Burkle posits that the "multidisciplinary mandate" of disaster management is well accepted but fails to meet expectations at the "front-end" meaning that a failure to articulate the multiple competencies which define this mandate prevent education, training, research, and field-level operational functioning to achieve a multidisciplinary character (Burkle, 2012:10).

Given the complexity and lack of standardization between tools, providing a turnkey system that still manages to integrate with legacy systems provides a significant integration challenge. To address these challenges, this study proposes a DSS that aligns with the current needs of EM stakeholders, bridging the capability gaps in existing systems, while also serving the entire EM lifecycle (cf. Altay and Green, 2006). As system development does not occur in a greenfield setting, the DSS solution is modular and scalable, with function-specific modules (described in Table 1), designed to integrate with existing systems to add value through advanced capabilities. The solution focuses on the challenges associated with a multi-agency response. Whereby, agencies often with no working history, a lack of a shared vocabulary, and an over reliance on internal structures and processes (Lee et al., 2011; Manoj and Baker, 2007; Carver and Turoff, 2007) have to work together coordinating/sharing information and resources (Bharosa et al., 2010; Mendonça et al., 2007).

To illustrate, the user can set the situation context with the situation module or select from current and historical situations and incidents (screenshot of DSS dashboard and situation control panel displayed in Figure 1). A situation represents the parent disaster type (e.g. avalanche, bacterial infectious disease, flood), which can have one or many associated incidents. Using this module, multiple major emergency events can be documented and displayed. As a result, strategic and tactical decision makers get a complete and highly granular picture of events. The custom developed DSS modules are designed to integrate using a model-view-presenter pattern whilst external third-party services and APIs are leveraged using Representational State Transfer (REST). RESTful services allow the system to access and manipulate online web resources. This means that external data can be requested and integrated with the system's situation object model. In practice, this means that all system modules can send data to the system's situation log which keeps track of all disaster-related data. Additionally, external web applications, such as online weather services, can be used to deliver situation-specific information to the system. From a user perspective, there is no difference between internal and external services. All content is tightly integrated with the system's user interface and can be leveraged for situational awareness. The architecture uses a modular design approach, with broadly self-contained units that provide tools and DS capabilities across the EM phases.

DSS Tools	Module	Description
Situation Context	Situation Module	Allows user to create new situations, provides easy access to all current & historical situations /incidents.
Information Management (mgt) Boards	Situation Log	Provides information manager with ability to record & send updates to the information management boards.
	Recognised Current Situation (RCS)	Information management capabilities & situational awareness for strategic-level decision-makers. Collaborative workspace that can be shared & edited remotely.
	Aims/Key Issues	Creates/presents strategic aims, priorities & key issues for the crisis.
	Actions Board	Creates time-sensitive actions; uses taxonomy to assign actions.
General Tools	GIS	INSPIRE compliant spatial database & planning functionality; provides relevant data sets & plotting capabilities.
	KMS	Organizational knowledge repository to store & surface relevant knowledge assets for RCS; based on the OpenKM platform.
	Data & Reporting	Data visualization; provides capabilities to import & display data from external sources e.g. hospital census data, inventory.
	Casualty	Template for managers to record casualty-related incident data.
	DS Mgt	Leverages project EM taxonomy to surface tasks, roles, resources, & materials based on incident type, EM phase, & country.
	Weather Module	Real time weather updates based on location; temperature, wind direction & air pressure.
	LMS	A cloud-based learning management system (LMS) to manage & deliver training resources. Leverages Moodle & COMPOD services.
	Report Tool	Quickly exports info. mgt screens to users as PowerPoint slides.
	Crisis Comm.	Compose & disseminate alerts easily to social media & public.
	Twitter Module	Observe incident-related content in real time; illustrate trending topics on maps; manage & display content from trusted users.

Table 1. DSS Module Descriptions

The developers implemented the modular architecture by designing the tools using the Model-View-Presenter pattern (a derivation of the Model-View-Controller pattern). Enhanced functionality between tools was achieved by following Java EE Event specifications to facilitate intra-modular communication. While each module on its own provides a level of functionality in its 'area of expertise' (Table 1), it is through the integration of modules that the full power of the system may be realized. In effect, DS is achieved through the use and combination of concurrent modules. Tools can be chosen depending on the context (e.g. type of disaster, location) of the current situation. To facilitate the communication between modules/components, the system uses a loosely-coupled, event-driven model where individual components can fire events and other components can subscribe to these events via listeners. As such, actions taken, and data gathered, in an individual tool, can be leveraged by other components. Events are handled, as appropriate, by methods within the various subscribers. The final system architecture integrates many components, and has been designed to be flexible enough to accommodate a number of different deployment strategies, including cloud-based instances, dedicated servers, and mobile light versions.

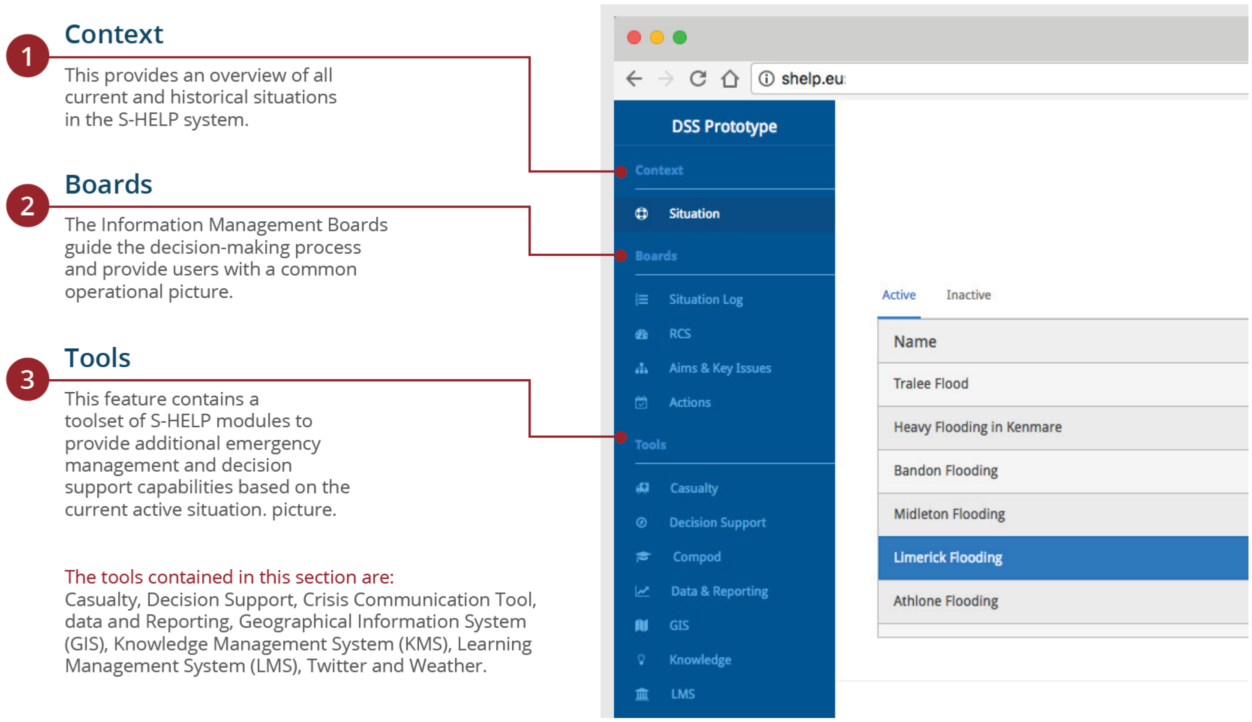

Figure 1. DSS Dashboard Layout

Action Design Research: User-Centered System Evaluation

ADR guided the research approach and was used to inform the evaluation of the developed DSS. ADR methodology draws upon both action research (AR) and DSR to design, develop, and evaluate IS intended for organizational practice. In the development research tradition, it is important to address both practice-driven and research-driven goals (Mathiassen, 2002). DSR aims to balance research rigor with practical relevance, while AR methods are useful for managing potentially contradictory goals of different stakeholders in research projects (Avison et al., 2001; Mingers, 2001). DSR abstracts knowledge to build and evaluate IT artifacts intended to solve specific problems in an application domain (Gregor and Jones, 2007), assessed based on a system's utility (Hevner et al., 2004). In contrast, AR investigates complex social processes and the introduction of a change to determine the effect on processes. Together, they see the artifact as a "black box" without an emphasis on the artifact itself, but instead its impact in the environment. DSR and AR complement each other to support the abstraction and innovation of an artifact, as well as the intervention and knowledge which emerges from its interaction in an environment. The paradigm accounts for both technological and organizational contexts of the artifact's design and use (Cole et al, 2005). ADR as prescribed by Sein et al. (2011) uses a four-stage process for: (1) problem formulation; (2) building, intervening and evaluation; (3) reflecting and learning; and (4) formalization of learning. The intervention may begin with researchers and expand to practitioner and end-user groups through alpha and beta versions (iterations of the abstracted artifact). The second stage of building, intervention, and evaluation integrates the intervals of DSR to emphasize the influential roles of technology and organizational environment in the formative evaluation of the artifact. A general principle of the methodology is the guided emergence of an artifact that is shaped by use from interactions with end-users and then reflected in the artifacts' redesign (Garud et al., 2008). In comparison to AR and DSR as separate paradigms, ADR keeps the artifact and its organizational impact central to inquiry, requiring participation of subjects in the research design.

As a result, the approach underpinning the work for understanding, executing, and evaluating the DSS solution incorporates the pillars of *relevance* to a practical problem and *rigor* in the line of inquiry;

informed by ADR (cf. Sein et al., 2011) and adapted from the "IS Research Framework" developed by Hevner et al. (2004). In line with this, the *EM environment* accounts for the business needs in terms of: (1) **stakeholders** (i.e. EM decision-makers; responders; EM agencies and inter-agencies coordination offices; developers/researchers; consortium partners; experts and advisory boards), (2) **processes** (i.e. existing standard operating procedures (SOPs); EM frameworks and workflows; and scenario/exercise guidelines), (3) **technology** (i.e. EM tools and projects; incident command system approach standards; and DS tools). Continuous evaluation of the EM sector and associated business needs informed system development to ensure research relevance. The complementary *knowledge base* is used to inform the research phases by providing applicable knowledge from appropriate: (1) **foundations** (i.e. EM challenges/models/tools; IS/DSS design and development; verification/validation approaches; analysis tools; ethics-by-design; Lean/KPI project management; learning theories; semantic and technical interoperability; cognitive needs of end-users; and crisis communication) and (2) **methodologies** (i.e. observation: focus groups, EM exercises, workshops, training; end-user focus groups and surveys; JAD sessions; prototyping sessions; practitioner-driven scenarios (tool demonstration and validation); and module and integration surveys). The close collaboration between the end-users and stakeholders from the EM environment and the theoretical underpinnings informing the research, ensure both external and internal validation are satisfied.

This paper focuses specifically on the approach to testing and evaluating the DSS using practitioner-driven scenarios. Thus, the DS evaluation can be classified as an ex-ante artificial evaluation based on the characterization presented by Venable (2012) and Pries-Heje et al. (2008). Due to the critical nature of disasters, it is not feasible to undertake a naturalistic evaluation of the DSS during an actual incident. Thus, an artificial evaluation was designed with two out of the three realities in place: (1) real users, (2) a real system, but with (3) an unreal problem created using scenarios (cf. Pries-Heje et al., 2008). To account for this, the scenarios have been designed based on real incidents and co-created with end-users and experts in the field of EM, detailed in subsequent sections. Furthermore, the evaluation is ex-ante as the DSS has yet to be implemented in a real-world setting (Pries-Heje et al., 2008; Venable, 2016) and is a formative three-phase evaluation executed throughout the IS development lifecycle, from partial prototype to integrated modular system. The focus of the evaluation is on the usability, utility, and integration of the DSS modules. The details of this evaluation are outlined in the following section.

Scenario Design and Evaluation Approach

This section outlines the design and development of the scenarios used in the DSS evaluation. Scenarios, in the EM literature, are used to support emergency planning and management and are defined as a "postdictive reconstruction of past events or, more commonly, a hypothetical construction of future ones" (Alexander, 2000, p. 89). They are deemed appropriate in the formulation of disaster plans, for assessing resources, and in testing individuals on their abilities to respond to practical problems, such as decision-making under stress (Alexander, 2000). An integrative scenario methodology should incorporate three approaches (Alexander, 2000): (1) traditional phased approaches of the EM lifecycle used with emergency plans and connectors between phases; (2) structured around key EM concepts (e.g. resource management or evacuation to predict events/outcomes); and (3) use of a hypothetical emergency to promote role playing and collaboration among participants. A scenario lays the foundation for an effective exercise, one that is intended to simulate a realistic sequence of events depicted through narratives and storylines. The exercises constitute a simultaneous and comprehensive test of emergency plans, system readiness, staff, procedures, equipment, materials, and training program needs (Perry and Quarantelli, 2005). The conduct, evaluation, and record of exercises are most appropriate in the areas of management and leadership, operational performance, and system performance (Gebbie et al., 2006). The engagement of appropriate stakeholders in the exercise planning stages best informs the design of the scenario narrative. Specialists with knowledge of organizational processes or emergency experience help ensure that realism and plausibility of a scenario are the focal point of its development. "A scenario that has been subject to this sort of quality assurance grants the exercise a higher degree of legitimacy in the eyes of exercise players which, in turn, allow them to focus on the exercise objectives rather than the realism of the scenario" (ECDC, 2014, p. 27). Hence, a steering committee, strategic exercise writing team, and operational exercise writing team were formed. The steering committee was responsible for: the management of the exercise; setting the exercise objectives; oversight of the writing teams; review of the exercise; and production of the exercise report and recommendations. The two exercise writing teams conducted detailed exercise planning throughout the project lifecycle, for the development and delivery of the operational, tactical, strategic objectives. Four primary documents were selected for suitability in guiding scenario design, namely: the U.S. Homeland Security Exercise and Evaluation Program; the ECDC Exercise Simulation Handbook; the Australian EMI's Managing Exercises Handbook; and the Irish Framework for Major Emergency Management (MEM).

Scenario 1: *Biological Hazard Response*	Scenario 2: *Cross-Border Chemical Explosion & Bio.*	Scenario 3: *Regional & Interregional Mass Flooding*
Preparation & Goals: ▪ Large-scale international public health emergency. ▪ DSS used for biological threat intelligence; decision-making; linking international countries. ▪ Established strategic advisory board for guidance. ▪ Comm. links with Israel & Ireland for notification of potential disease spread. ▪ DSS supporting health officials with difficult ethical considerations. **Implementation:** ▪ Hybrid drill/tabletop cross-border scenario: two exercises scheduled. ▪ First exercise was a test for larger bio. incident. ▪ Exercise representatives from: prehospital emergency services & health maintenance & Ministry of Health. **Validation of Results:** ▪ Debrief: questionnaires to determine key lessons-learned, observers used to monitor progress & inject new variables to replicate changing scenario. **Evaluation of DSS:** ▪ Review tools to link incident type & supporting decisions. ▪ Determine how DSS is used to map response & projected evacuation.	**Preparation & Goals:** ▪ Command & control established for health officials from Northern Ireland (UK) & Republic of Ireland (ROI). ▪ DSS supported decision-making of participants. ▪ DSS allowed bilateral comm. links. ▪ IM Boards enabled RCS overview for jurisdictions. ▪ Importing of modelling data for silver & tactical commanders to view effects of toxic plume. ▪ Discussion of response policy & potential influence of DSS. **Implementation:** ▪ Hybrid drill/tabletop cross-border scenario. ▪ A cross-border exercise design team developed an exercise that met the needs of end-users & demonstrated DS capabilities of tools. **Validation of Results:** ▪ Debrief: a standard after-action report prepared to incorporate lessons-learned & determine the effectiveness of the tools. **Evaluation of DS S:** ▪ Review DS tools used. ▪ A walkthrough tabletop exercise was designed for strategic decision-makers from two countries.	**Preparation & Goals:** ▪ Project team evaluated response of two regions (Cork/Kerry). ▪ Tested impact of decision-making & intelligence gathering. ▪ Decision-making EM skillset incorporated into scenario. ▪ Threat analysis tool. ▪ Demonstrated inter-agency management of incident. ▪ Established comm. links with governmental agencies in the Department of Defence (Dublin). ▪ Tested integration of international knowledge, & inter-agency comm. & cooperation. ▪ Participants evaluated DSS against their current tools' usability & utility. **Implementation:** ▪ Tabletop exercise designed to demonstrate & validate DSS. ▪ Inter-agency exercise design team established to design/develop flood scenario. **Validation of Results:** ▪ Development of assessment, debrief, lessons-learned, communication of learning outcomes & determine how to increase results sustainability. **Evaluation of DSS:** ▪ Review DS tools used & impact on decision-makers. ▪ Creation & use of common operational picture, projecting evolution, recording of actions & tracking progress. ▪ Projection models & level of coordination achieved with DSS.

Table 2. Scenario Design and Implementation Detail

The general guidelines from these documents were used to inform the exercises, but ultimately, the three end-user partners selected the Irish Framework, as it was deemed the best fit for the countries involved. The framework describes the required oversight bodies and responsibilities for the management of exercises as well as guidance for the delivery. Consequently, three scenarios were created: (1) Biological Hazard Response, (2) Cross-Border Chemical Explosion and Bio-Hazard, and (3) Regional and Interregional Mass Flooding (details in Table 2). The scenario exercises focused on high-level decisions and concepts that emergency managers had to consider in response to these events, which would result in staffing/supply impacts and difficulty maintaining operational status. These progressive scenarios and corresponding prompts aided and facilitated the exploration of emergency managers in using the DSS at local, regional, and national levels, while also reviewing current EM fundamentals, emergency planning process, the role of cross-border mutual aid, and emergency public information. Ultimately, the scenario exercises highlighted the need for a networked approach to preparedness and response and the benefits of using an integrated system when dealing with a major emergency. For the system evaluation, the objectives of the scenarios were to: (1) demonstrate and review the DSS with end-users; (2) gather debriefing data, lessons-learned, and expert feedback; and (3) ensure continuous improvement for module usability and utility.

Three Phased Data Collection

The scenarios enabled a three-phased data collection and analysis protocol, using both quantitative and qualitative methods. The quantitative methods comprised survey questionnaires (evaluation forms), and qualitative included: participant observation (notes and videos); survey comments (open-ended); and general feedback (focus groups and discussions with developers). Thus, the DSS was systematically implemented and evaluated using three scenarios beginning in September 2016. During the implementation periods, end-users representing first responder agencies were presented with the solution. Depending on the type of questions and results to be generated, different “communities” (e.g. medical experts, hospital operators, first responders, national and international representatives, etc.) were involved in the validation processes in their different roles. Participants were observed while interacting with the system, and evaluation forms collected their impressions of system functionality. Typeform (an online program) was used to collect feedback during Scenario 1 and 2. However, user feedback prompted paper-based questionnaires for the final scenario and resulted in more consistent respondent participation. Each scenario required the use of different modules, depending on module completion and the underlying narrative. As a result, the biological scenario administered seven surveys, the chemical scenario eight, and the flood scenario nine. This resulted in data from 24 surveys from 85 participants (473 individual surveys).

Scenario 1: Biological Hazard Response

The first scenario took place in Magen David Adom (MDA) headquarters in Tel-Aviv, Israel on 26th September 2016 (Table 3a). The scenario simulated the spread of a respiratory virus across Europe to assess the performance of the DSS in the management of a cross-border pandemic. With unpredictable frequency, novel influenza viruses emerge/re-emerge to cause an influenza pandemic. When this happens, it is likely that global spread will ensue rapidly, affecting large numbers because of little or no immunity to the strain. However, until such an event occurs, the impact (expressed as the severity of the illness) and proportion of the population most severely affected is unknown. As a guide, the impact could range from a 1918-type pandemic, with severe disease mainly in young adults, to a 2009 pandemic, with mild illness in most population groups. Given the unpredictable nature, the response must be flexible and proportionate. This scenario built on current business continuity arrangements, while addressing the high-level decisions and concepts that hospitals, emergency responders, and public health officials would need to consider, which would result in staffing/supply impacts. The scenario comprised twelve injects spanning a timeframe of eight months from July 2016 to March 2017. Injects are commonly used in scenario planning to prompt action and decision making and represent critical information necessary for decision making. The evaluations used a number of injects including weather data, geographic information and first responder reports to drive the exercise scenarios. Photographs, sound and custom news footage were used to enhance the realism of the situation. Based on these injects, the DSS provided a shared workspace to visualize this data and formulate “Strategic Aims and Priorities” and “Key Issues”. Modelling capabilities within GIS, combined with emergency plans in the KMS, could also be used to track the spread of the virus and prompt the assignment of “Actions”. The biological injects were based on the 2008 avian influenza biological threat H5N1.

Table 3a: Biological Scenario				**Table 3b: Chemical Scenario**				**Table 3c: Flooding Scenario**			
Role/Org.	***No.***	***Focus***	***No.***	***Role/Org.***	***No.***	***Focus***	***No.***	***Role/Org.***	***No.***	***Focus***	***No.***
Observers	6	RCS	8	Observers	8	RCS	20	Observers	11	RCS	37
Project Manager, Emergency Dept MOH	1	Situation Module	7	EM Officer, EU Projects Coordinator, HSE	1	Situation Module	29	Police Sergeant	3	Situation Module	37
Epidemiologist, Public Health Office, MOH	1	GIS	6	EM Manager & EM Manager & Coordinator,	2	GIS	16	Irish Civil Defence	1	Log	37
Biological Dept., Ministry of Defence	1	KMS	6	Slyne & Co	2	KMS	23	Cork City Council	2	Aims & Key	37
Field Training Officer, MDA	2	Data & Reporting	6	EM Officers, Dept. of Health Northern Ireland	2	Data & Reporting	14	Cork County Council	1	Actions Board	37
Officers, EM Dept., MDA	4	Casualty	7	Emergency Planning Coordinator – South	1	DS Management	8	Cork/Kerry Healthcare	3	GIS	36
Medical Lead/EU Project Officer, MDA	1	Integrated Tool-set	7	Manager, Western Area Emergency Planning	1	Weather Module	8	National Ambulance	3	KMS	36
Head of Disaster Management Dept.	1			Officer, Western Area Emergency Planning Group	1	Integrated Tool-set	10	Enterprise Ireland Security NCP	1	LMS	6
				Western Health & Social Care Trust	2			Resilience City Planning Consultancy	1	Integrated Tool-set	35
				Manager, Public Health Agency Northern Ireland	1			HSE Emergency Management	3		
				Officer, Dublin Fire Brigade	3			HSE Inter-agency EM Office	1		
				EM Planner, HSE	3			Kerry Council	1		
				Saadian Technologies	1			Defence Forces	3		
				Resilience City Planning Consultancy	1			Slyne & Co	2		
				Fire & Rescue Service, Cork City	2			St John Ambulance	1		
Totals	**17**		**47**		**31**		**128**		**37**		**298**

Table 3. Scenarios: Participant Details and Survey Responses

Scenario 2: Cross-Border Chemical Explosion and Bio-Hazard Scenario

The second scenario was designed to test the DSS in a cross-border situation (Table 3b). It was constructed to incorporate lessons-learned from the biological exercise in Israel. The scenario characterized a cross-border chemical explosion, simulated on the 26th October 2016 in the National Emergency Co-ordination Centre (NECC) in Dublin, Ireland. The objective was to demonstrate the DSS in an appropriate setting for strategic decision-makers of the NECC. The approach was to use several seemingly unrelated emergency events. Firstly, the nationwide distribution of a defective illicit drug that resulted in the inundation of intensive care units across the hospital network. Secondly, was an explosion in a drug manufacturing plant in Strabane, Northern Ire-land, which required the coordination and collaboration of agencies across state boundaries (i.e. ROI and UK). To conduct the exercise within the period established, certain events were accelerated. Data collected from actual events were applied and utilized (e.g. Fire at a Belfast recycling plant on 1st September 2016).

Scenario 3: Regional and Interregional Mass Flooding

The final scenario took place on the 25th November in the Emergency Co-ordination Centre at Anglesea Street Fire Station, Cork, Ireland (Table 3c). The objective was to test the decision-making capabilities of participants using the DSS. Unlike the other scenario exercises, the flooding participants agreed to utilize the DSS as a method of testing their own flood response plans in preparation for winter 2016. Flooding arises from a combination of natural physical conditions and human activity, often accompanied by poor weather conditions and lasting for an un-certain period. For practical reasons, the impacts of flooding in the present context includes: threat to safety or health of persons; serious damage to property or infrastructure; and major social or economic impact. Flood events vary in nature, scale, and duration, and response agencies may not have adequate resources to alleviate all impacts.

Responders may have to work in dangerous conditions, considerable numbers of people may be displaced from their homes, and businesses/utilities interrupted. The flooding scenario comprised twenty injects based on real life emergency situations, which occurred in Cork in 2009, 2011, and 2014; each of which incurred severe damage to the city. It was a five-day time frame, from initial warnings on Monday of expectant severe weather to the advent of the major flooding event Friday evening.

Data Analysis

The evaluation forms consisted of 12 common statements to be rated using a 7-point type Likert scale and one open-ended question (to gather general comments). The surveys were aimed at addressing the usability and utility of the demonstrated modules. Usability related to perceived ease-of-use and the ability for users to quickly and easily understand and learn the capabilities and functionality of the system. Utility related to perceived usefulness based on the value of the designed capabilities and functionality for strategic-level decision-makers, as well as the ability of the system to enhance performance, productivity, and user effectiveness. The survey statements were derived and tailored from the system evaluation literature, including the Technology Acceptance Model (Davis, 1989) and the System Usability Scale (Brooke, 1996). These scales are used to effectively evaluate user perceptions on new systems in specific contexts. At the end of each scenario a survey on the integration of the tool-set was collected. The Likert-type scale results in ordinal data, where responses can be rated or ranked but the distance between responses is not measurable (Sullivan and Artino, 2013); therefore, the average cannot be used as a measure of central tendency. Hence, different types of analysis were employed to understand the data distribution. Frequency distributions were created to display the ratings across the different survey statements. The scale has 7 points representing 1 strongly disagree, 4 neutral, and 7 strongly agree. Thus, 1 to 3 are considered “disagreement” (strongly disagree, disagree, disagree somewhat) and 5 to 7 are considered “agreement” (agree somewhat, agree, strongly agree). The average or mean was calculated based on the scales of agreement and disagreement to summarize and compare the frequency distributions. Further analysis was undertaken to calculate the total agreement (TA) percentage and total net agreement (TNA) percentage. TA is calculated from the selection of the top three agreement scales (i.e. 5 to 7). TNA subtracts the equivalent three disagreement scales (i.e. 1 to 3) from the TA percentage. In addition, to ensure reliability of the data, this was compared with the "top 2 box" rating score, which excludes the "neutral" and "somewhat" ratings from the analysis, only including the strongest indicators of agreement (i.e. 6 and 7) and disagreement (i.e. 1 and 2). Within and cross-case comparisons were conducted from a usability, utility, and integration perspective, while also drilling down into a statement-level analysis to identify deviations in the data.

System Evaluation Findings

This section presents a summary of the findings for (1) usability, (2) utility, and (3) the integrated tool-set. The findings are discussed across the three scenarios, before delving into a statement-level analysis that identifies specific areas for improvement. Due to space constrictions, only a selection of the data is included with a sample of the analysis to illustrate the findings. For example, Figure 3 presents the mean of usability and utility for each module/scenario based on the TNA. For *usability*, the mean TA ranged from 69% to 92% across all surveyed modules. This indicated a high level of agreement with the usability statements. To ascertain areas of disagreement, TNA ranged from 48% to 83% (see Figure 2), further indicating relatively high usability perceptions overall. Only six of the modules fell below 60% TNA for usability. These ratings are explained with the statement-level analysis presented in Figure 4, which highlights in red the specific statements that fell below 50% TNA. This data was used to identify areas for improvements across the modules. Two statements in particular received low ratings overall: the need for written instruction (lower scores for 10/12 modules) and the need for support from a technical person (lower scores for 8/12 modules).

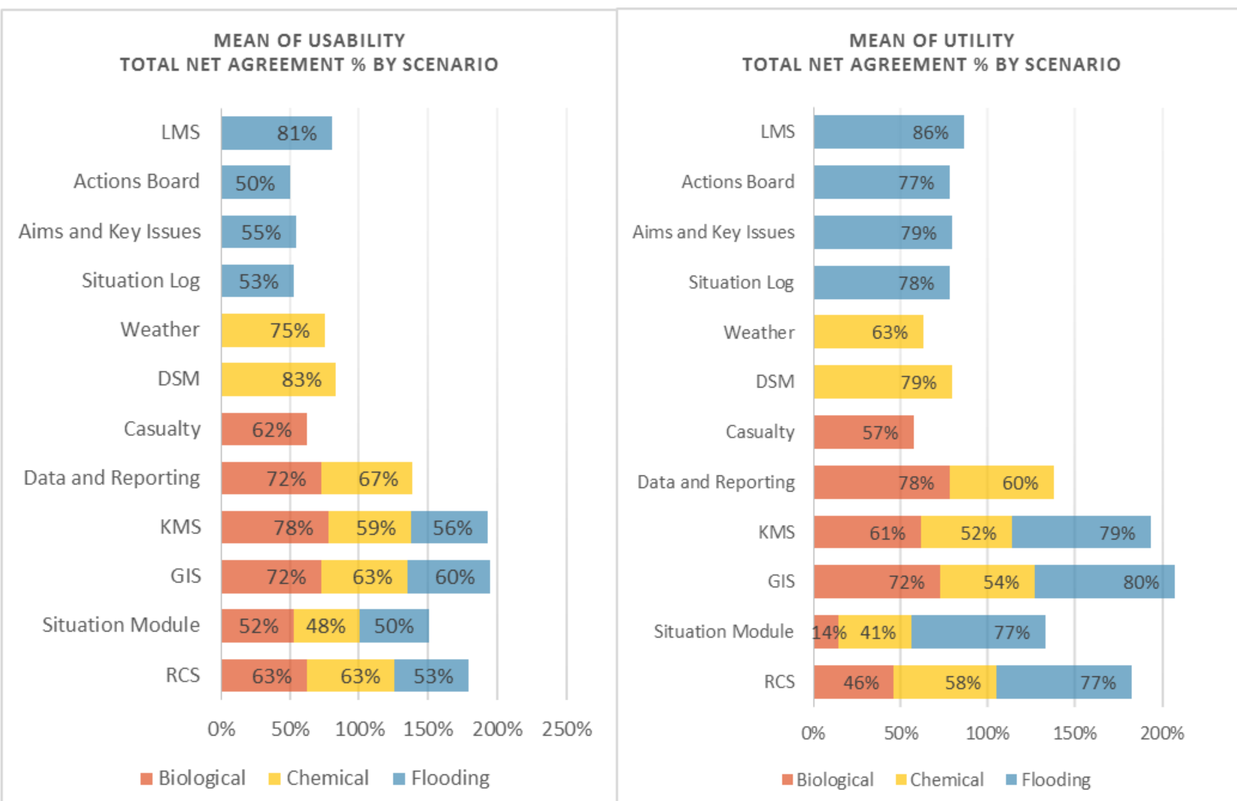

Figure 2. Usability and Utility Total Net Agreement by Scenario

This analysis also identified three modules (i.e. Situation Module; Casualty; and Actions Board) with lower scores across three usability measures for the aforementioned statements and concerning perceptions of module complexity. However, in general, the other usability scores across modules remained stable or improved over time with each subsequent scenario. For *utility*, the mean TA percentages ranged from 57% to 90% across all modules. This indicated a high level of agreement with the utility statements. To ascertain areas of disagreement, the TNA ranged from 14% to 86% (see Figure 2), highlighting variability across the figures, particularly for the Situation Module. In general, the other modules displayed relatively high utility perceptions overall. Utility perceptions fell below 60% TNA for five of the modules. These ratings are explained with the statement-level analysis, which highlights in red the specific statements that fell below 50% TNA in each scenario (Figure 4). Overall, from this analysis, 10 of the 12 modules received high utility scores by the final evaluation, with significant improvements identified from each scenario. Two modules (i.e. Data & Reporting and Casualty Board) had lower scores in terms of: perceived usefulness; value for regular and occasional users; and requirements matching. This can be explained by the fact that many of the participants were at different levels of the organization and the Data & Reporting module is designed for strategic-level decision-makers and less appropriate for end-users at the operational level. This was clarified through participant feedback, with one respondent stating: "Not quite applicable to my service so can't really effectively comment". Further to this, the focus groups with strategic-level decision-makers cited it as one of the most beneficial tools. Likewise, the Casualty module has a specific role-based emphasis and thus may not have been as useful to some of the participants.

		Usability Total Net Agreement %						Utility Total Net Agreement %					
Scenario	Module	This module is easy to use	...presents information in a clear and understandable manner	I can use it without written instructions	I did not find the module unnecessarily complex	I do not...need the support of a technical person to be able to use...	It would be easy for me to become skillful at using...	This module's capabilities meet my requirements	I would find this module useful in my job	...has value for both occasional and regular users	I think that I would like to use this module/tool frequently	support emergency tasks in stressful situations	...enable me to accomplish tasks more quickly
Biological	RCS	75%	50%	75%	50%	50%	75%	50%	25%	50%	50%	50%	50%
Chemical	RCS	60%	60%	70%	60%	60%	70%	50%	50%	80%	60%	80%	30%
Flooding	RCS	81%	89%	22%	51%	-3%	78%	86%	76%	86%	68%	86%	62%
Biological	Situation Module	71%	71%	43%	14%	14%	100%	43%	-14%	43%	14%	-14%	14%
Chemical	Situation Module	45%	59%	10%	59%	45%	72%	52%	31%	52%	52%	31%	31%
Flooding	Situation Module	76%	81%	14%	43%	5%	78%	86%	73%	92%	68%	81%	62%
Biological	GIS	100%	67%	100%	67%	33%	67%	67%	67%	67%	67%	67%	100%
Chemical	GIS	75%	63%	75%	75%	25%	63%	63%	50%	63%	38%	63%	50%
Flooding	GIS	89%	83%	28%	69%	8%	83%	92%	89%	81%	69%	86%	64%
Biological	KMS	67%	33%	100%	67%	100%	100%	33%	67%	67%	67%	67%	67%
Chemical	KMS	57%	48%	48%	74%	65%	65%	30%	48%	65%	57%	65%	48%
Flooding	KMS	75%	75%	33%	58%	11%	81%	69%	89%	78%	64%	89%	86%
Biological	Data & Reporting	100%	100%	67%	33%	67%	67%	100%	67%	33%	67%	100%	100%
Chemical	Data & Reporting	71%	86%	43%	71%	71%	57%	57%	43%	43%	57%	86%	71%
Biological	Casualty	100%	100%	14%	43%	14%	100%	43%	43%	14%	71%	100%	71%
Chemical	DSM	100%	100%	50%	100%	50%	100%	75%	75%	75%	75%	100%	75%
Chemical	Weather	75%	75%	75%	75%	75%	75%	75%	50%	75%	50%	75%	50%
Flooding	Situation Log	81%	84%	19%	51%	5%	76%	84%	75%	92%	70%	84%	62%
Flooding	AKI	81%	89%	16%	54%	8%	78%	92%	76%	89%	70%	84%	62%
Flooding	Actions Board	78%	81%	16%	49%	-3%	78%	84%	76%	86%	70%	86%	62%
Flooding	LMS	83%	100%	33%	100%	67%	100%	83%	100%	100%	83%	67%	83%

Figure 3. Usability and Utility TNA Statement-level Matrix

For the evaluation of the integrated tool-set, the TA and TNA scores were compared across the scenarios. The biological scenario had the greatest variation with 71% TA versus 51% TNA. Whereas, both the chemical and flooding scenario saw a smaller decrease from 74% to 65% and 79% to 68% respectively. Overall, this indicated a high level of agreement with the integration statements. At the statement-level analysis, perceptions were high for five (of seven) integration statements in the final evaluation, showing improvements from both the biological and chemical evaluations in terms of integration aspects, skillset acquisition, decision-making efficiency, and both efficiency for coordination and collaboration between agencies in a country and across national borders. Lower scores were associated with perceptions of ease-of-use (46% TNA) and user confidence (20% TNA). This result was offset by the high scores in the belief that the skills to use the tool-set can be learned quickly (74% TNA), and the usability findings that identified the need for written instructions and support from a technical person when using the modules. Thus, training has been acknowledged as an important aspect for future DSS implementation.

Discussion of Evaluation Findings and Participant Feed-back

The results of the evaluation showcased the high level of agreement for perceptions of usability, utility, and the integration of the DSS solution. Many of the issues raised in the biological and chemical scenario were addressed by the final evaluation. Feedback from participants was used to inform system improvements, with suggestions for new capabilities matched against project requirements and validated by end-user partners. Ultimately, agreement scores improved with each scenario and ratings were high across the modules. The evaluation highlighted that as the system neared completion (with capabilities added to the tool-set), the need for training, written instructions, and support from a technical person when implementing the solution is necessary. All other areas of perceived ease-of-use and perceived usefulness improved, confirming the utility of the DSS. Thus, the scenarios provided an invaluable opportunity to demonstrate and validate each module of the tool-set with different types of EM stakeholders. The scenario, which provided a backdrop and opportunity to demonstrate the system, was also appraised by participants who confirmed its' value: "The scenario was realistic and helped show how the tools could be used"; "It was learning by doing. Far better than just being told… the output…it was possible to interact. It was an exceptionally good approach"; and "Without the scenario…understandings would have been both poor and varied". This study confirms the important role of scenarios in development for validating system design (cf. Benner et al., 2014), as well as the benefits of using realistic scenarios to structure emergency exercises (cf. Alexander, 2000). This study provides details of how to design and implement scenarios for system evaluation in the context of the EM domain, which can be applied to system development in other healthcare and emergency disciplines.

Valuable insights from participants were also garnered during the scenario evaluations. Participants stated: "Well done, impressive, relative to other tool-sets I have experienced from other EU projects as a trained and experienced Information Manager, I find the module easy to navigate and use. I would happily use in the event of an emergency to update my information as required and support actions in crew deployment." and "It's an excellent system – tools can be used in many situations. Well researched and user-friendly. The system is generally beneficial for an information gathering perspective and for the defense forces to have insight into the extent of any major emergency […]" Regarding the KMS, one participant from the police force stated that the "[…] comms room would greatly benefit from this system – especially when dealing with deaths or critical incidents". Although the final scenario specified a flood, the application of the system beyond this use-case was apparent to some participants. Participants reacted to the RCS module, a central element of the DSS, by stating it provides a "more effective method of inputting data" and "presents information in a systematic way"; these individuals felt the RCS would support effective decision-making with appropriate training supports. Many of the participants believed adoption to be instrumental: "I think [the DSS] would be particularly beneficial if it was adopted by all agencies." and "I think there is a strong case to expand this tool but feel it's critical that all agencies are using the same thing, would be great if adopted by EU." Some participants identified potential barriers to implementation, highlighting the need for a high level of encryption/security with the inclusion of a "classified system" that defined specific roles and authorization and also accounted for country-specific security considerations. Moreover, it was important to the participants that there would be no technological barrier with how the DSS connects to other systems and databases. Much of the feedback was incorporated and even resulted in the development of additional capabilities/modules, an example of which is the Report Tool (finalized after the flooding scenario and thus not included in the evaluations). Likewise, the experience and feedback after each scenario fed into the design of subsequent scenarios and resulted in several lessons-learned and observations in the context of DSS for EM. Proactively integrating lessons-learned into the process and turning them into actionable items is important. After action reports and similar post-evaluations identify recurring problems, but this recurrence suggests the need for identifying process improvements over time to ensure that lessons-learned are not repeated. The implementation of an appropriate DSS enables emergency managers to effectively identify valuable lessons from emergencies and appropriately incorporate these items into training exercises for future emergencies. The DSS solution supports this end, and through practitioner-driven scenarios, the needs of EM stakeholders were elicited, collected, and incorporated.

Conclusions and Limitations

This paper presented the evaluation of a DSS developed to address current EM challenges and the needs of relevant stakeholders based on an all-phases approach to EM. The DSS solution is a modular system, specifically designed to be mixed and matched with existing systems. This enables the system to better address the needs of end-users, who can select modules based on their own requirements and existing infrastructure. The modules were designed to address the capability gaps identified in commercially available systems, and moreover, support the growing need for system interoperability in the event of cross-border emergencies. The solution builds on the needs of the domain and includes the automation of paper-based EM processes that utilize whiteboards and other static information capture techniques. The evaluation of the DSS used multiple methods of assessment to triangulate the data and gain better insights into the tool-set validation. There is data from 24 evaluation surveys (473 individual surveys), as well as participant feedback and observations. In addition, the scenarios were developed to test various modules and the integration of the tool-set as whole, facilitating the evaluation from three different emergency contexts and testing the tools on an international scale. The primary limitations of the scenarios included the varied emergency preparedness/response background of exercise participants, their roles at the individual and organizational levels, as well as the recognition that few agencies have individuals funded to perform emergency preparedness duties independently of their other job. The evaluation was also constrained by the design of the exercises, which were artificial in nature but designed to be as challenging as possible while testing the appropriate tools. Although the evaluation could not recreate stress associated with a real-life emergency situation, the user interface of the DSS was informed by research carried out by Steiner et al. (2017) who provide a psychological framework and design principles that provide a deeper understanding on cognitive processing and decisions making in emergencies. Further studies could be conducted to evaluate these design principles on specific interaction within modules. Similarly, not all tools could be evaluated during each scenario due to exercise limitations and time constraints. Furthermore, there is a bias associated with the use of ADR methodology that places the development partner as a part of the evaluation process. To address this and reduce any potential bias, the developers collaborated with the end-user partners in the development and execution of the scenarios. Moreover, the iterative development and feedback loop reduced any bias by being user-centered and based on a rigorous validated knowledge base. This included internal and external validation checks with the help from an external advisory board. Another limitation resulted from the fact that much of the scheduling had to be organized around the participants' timetables, thus pre-training had its own time constraints. All participants were given user guides to train at their own discretion in advance of the scenario. In conclusion, the aim of the scenarios was to provide end-users with an opportunity to evaluate the DSS in line with their own current response concepts, plans, and capabilities and further identify enhancements to cross-border events, major flooding, and infectious disease emergencies. The scenario exercises focused on strategic-level decision-maker actions during various events, while also providing an opportunity for further enhancement of inter-agency relationships between service providers. This study combined research rigor with the EM sectors' needs to enhance practical relevance and address the need for industry-focus in IS research (cf. Chiasson and Davidson, 2005). The end-user was an active participant in the process; putting usage experience and utility center stage (cf. Brenner et al., 2014). As a result, the evaluation methods served to validate the developed solution and highlight new and interesting perspectives from which to continue system improvements and implement future plans.

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